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(54) Dot substitution to compensate for failed ink jet nozzles

(57) An ink jet printer and a method of operating an ink jet printer wherein inoperative true black printing nozzles are detected, and substitute dots formed of non-black are printed at pixel locations that normally would be printed with the inoperative true black printing nozzles if such nozzles were operative. Each substitute dot comprises one or more constituent non-black dots, and in accordance with one implementation, each substituted dot comprises a composite or process black dot formed of two or three of cyan, magenta or yellow inks.

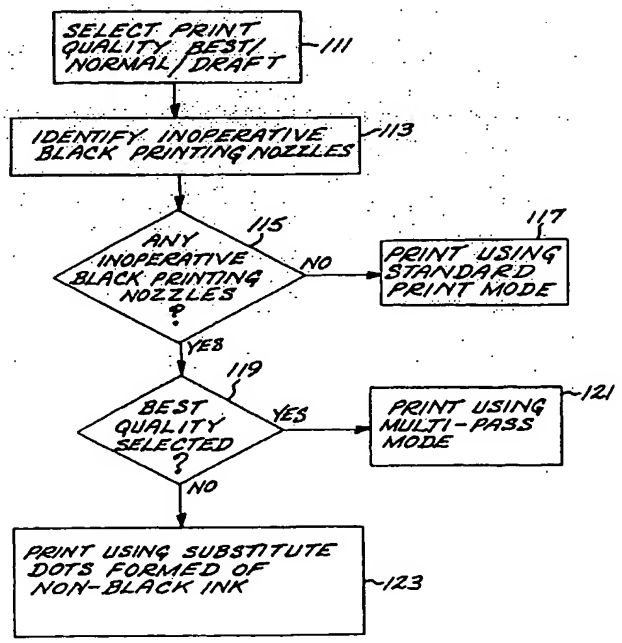

FIG.8

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Description

BACKGROUND OF THE INVENTION

[0001] The disclosed invention relates to ink jet printing devices, and more particularly to techniques for maintaining throughput when inoperative nozzles are present.

[0002] An ink jet printer forms a printed image by printing a pattern of individual dots at particular locations of a pixel array defined for the printing medium. The locations are conveniently visualized as being small dots in a rectilinear array. The locations are sometimes called "dot locations," "dot positions," or "pixels". Thus, the printing operation can be viewed as the filling of a pattern of dot locations with dots of ink.

[0003] Ink jet printers print dots by ejecting very small drops of ink onto the print medium, and typically include a movable carriage that supports one or more printheads each having ink ejecting nozzles. The carriage traverses over the surface of the print medium, and the nozzles are controlled to eject drops of ink at appropriate times pursuant to command of a microcomputer or other controller, wherein the timing of the application of the ink drops is intended to correspond to the pattern of pixels of the image being printed.

[0004] Color ink jet printers commonly employ a plurality of printheads mounted in the print carriage to produce a full spectrum of colors. For example, in a printer with four printheads, each printhead can provide a different color output, with the commonly used base colors being cyan, magenta, yellow and black. In a printer with two printheads, one printhead provides a black output, while the other provides cyan, magenta and yellow outputs from respective nozzle sub-arrays.

[0005] The base colors are produced on the media by depositing a drop of the required color onto a pixel location, while secondary or shaded colors are formed by depositing multiple drops of different base colors onto the same or an adjacent pixel location, with the overprinting of two or more base colors producing the secondary colors according to well established optical principles. That is, dots of a base color are produced by depositing a drop of the required color, while dots of secondary or shaded colors are formed by depositing multiple drops of different base colors. A dot of a secondary or shaded color can also be considered as a plurality of overlapping dots each of which is of a base color.

[0006] A consideration with ink jet printers that include black printing nozzle arrays and non-black color printing nozzle arrays is the failure of one or more black printing nozzles, which if not compensated would result in image defects such as missing lines in black areas such as text. A known compensation technique is multiple pass print modes, which results in increased print times and decreases in throughput.

[0007] Accordingly, there is a need to compensate for black printing nozzle failures in a manner that avoids decreases in throughput.

SUMMARY OF THE INVENTION

[0008] The disclosed invention is directed to an ink jet printer wherein inoperative black printing nozzles are detected, and substitute dots formed of non-black ink are printed at pixel locations that normally would be printed with the inoperative black nozzles, wherein each substitute dot formed of non-black ink is formed by at least one constituent non-black dot. In accordance with a specific aspect of the invention, the substitute dots formed of non-black ink comprise composite or process black dots formed of two or more constituent non-black base colors. For example, such non-black base colors are selected from cyan, yellow, or magenta.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The advantages and features of the disclosed invention will readily be appreciated by persons skilled in the art from the following detailed description when read in conjunction with the drawing wherein:

FIG. 1 is a perspective view of an ink jet large format printer/plotter incorporating the teachings of the present invention.

FIG. 2 is a perspective view of the carriage assembly, carriage positioning mechanism, and print media positioning mechanism of the printer/plotter of FIG. 1.

FIG. 3 is a simplified perspective view of a media positioning system of the print/plotter of FIG. 1.

FIG. 4 is a perspective view of a another print carriage that can be employed in the printer/plotter of FIG. 1.

FIG. 5 is a perspective view of a further print carriage that can be employed in the printer/plotter of FIG. 1.

FIG. 6 is a simplified block diagram of a printer controller for controlling the swath printer of FIG. 1.

FIG. 7 schematically depicts a pixel array on which dots are selectively printed by the printer of FIG. 1.

FIG. 8 sets forth a flow diagram of an illustrative procedure of operating an ink jet printer in accordance with the invention.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0010] In the following detailed description and in the several figures of the drawing, like elements are identified with like reference numerals.

[0011] FIG. 1 is a perspective view of an ink jet large format printer/plotter 10 incorporating the teachings of the disclosed invention by which inoperative black printing nozzles are compensated without decreasing throughput.

[0012] The printer 10 includes a housing 12 mounted

on a stand 14. The housing has left and right drive mechanism enclosures 16 and 18. A control panel 20 is mounted on the right enclosure 18. A carriage assembly 100, illustrated in phantom under a cover 22, is adapted for reciprocal motion along a guide rail 24, also shown in phantom, which is parallel to a carriage scan axis, whereby the carriage assembly 100 moves along the carriage scan axis. The position of the carriage assembly 100 in the carriage scan axis (or horizontal axis) is determined by a carriage positioning mechanism 110 (FIG. 2) with respect to an encoder strip 120 (FIG. 2) as discussed more fully below with respect to FIG. 2. A print medium 30 such as paper is positioned along a vertical or media axis by a media axis drive mechanism that includes a print roller 154 (FIGS. 2 and 3).

[0013] FIG. 2 is a perspective view of the carriage assembly 100, the carriage positioning mechanism 110 and an encoder strip 120. The carriage positioning mechanism 110 includes a carriage position motor 112 which has a shaft 114 extending therefrom through which the motor drives a small belt 116. Through the small belt 116, the carriage position motor 112 drives an idler 122 via the shaft 118 thereof. In turn, the idler 122 drives a belt 124 which is secured by a second idler 126. The belt 124 is attached to the carriage assembly 100 and adapted to slide therethrough.

[0014] The position of the carriage assembly 100 in the carriage axis is determined precisely by the use of the encoder strip 120. The encoder strip 120 is secured by a first stanchion 128 on one end and a second stanchion 129 on the other end. The encoder strip 120 may be implemented in a manner disclosed and claimed in commonly assigned U.S. Patent No. 5,276,970, which is incorporated herein by reference. As disclosed in the reference, a carriage axis encoder having an optical reader is disposed on the carriage assembly and provides carriage position signals.

[0015] The carriage assembly 100 removably supports four ink jet printhead cartridges or pens 102, 104, 106, and 108 that store ink of different colors (e.g., black, yellow, magenta and cyan ink, respectively). As the carriage assembly 100 translates along the carriage scan axis, selected ink firing resistors of the printheads of the printhead cartridges 102, 104, 106 and 108 are activated such that ink drops are fired through associated ink jet nozzles.

[0016] FIG. 3 is a perspective view of a simplified representation of a media positioning system 150 utilized in the printer of FIG. 1. The media positioning system 150 includes a media axis motor 152 that drives the print roller 154. The position of the print roller 154 is determined by a media position encoder 156. The media position encoder 156 includes a disc having a plurality of apertures 159 therein. An optical reader 160 provides a plurality of output pulses which facilitate the determination of the position of the print roller 154 and, therefore, the position of the print medium 30 (FIG. 1) as well. Position encoders are well known in the art. See for example, Economical High-Performance Optical Encoders by Howard C. Epstein et al., published in the Hewlett-Packard Journal, October 1988, pages 99-106.

[0017] As also shown in FIGS. 1, 2 and 3, an optical sensor module 200 is mounted on the carriage assembly 100. The sensor module optically senses test lines printed by a printhead to determine printhead cartridge misalignments so that they can be corrected or compensated. By way of illustrative example, the sensor module 200 is implemented with a phase plate, and suitable processing circuitry is provided for processing the output thereof, as disclosed in commonly assigned U.S. Patent 5,404,020, incorporated herein by reference.

[0018] Referring to FIG. 4, a modified print carriage 100a carries a removably mounted single color ink cartridge 130 (e.g., black printing) and a tri-compartment ink cartridge 132 that includes separate reservoirs 133, 134, 136 for different color inks such as cyan, magenta and yellow.

[0019] Referring to FIG. 5, a further modified print carriage 100b carries a first tri-compartment ink cartridge 140 which has separate ink reservoirs 142, 144, 146 for different color inks such as yellow, light magenta, and dark magenta. A second adjacent tri-compartment ink cartridge 150 includes separate ink reservoirs 152, 154, 156 for different color inks such as black, light cyan, and dark cyan.

[0020] Referring now to FIG. 6, set forth therein is a simplified block diagram of a control system for controlling the thermal ink jet printer of FIG. 1 in which the techniques of the invention can be implemented. The control system includes an interface 51 which receives print data from a host computer, for example, and stores the print data in a buffer memory 53. A microprocessor controller 55 is configured to process the print data to produce raster data that is stored in a bit-map raster memory 57a contained in a random access memory (RAM) 57 provided for the use of the microprocessor controller 55. A read-only memory 59 is also provided as appropriate for the use of the microprocessor controller 55.

[0021] A print controller 61 transfers portions of the raster data from the bit-map raster memory 57a to a swath memory 63 and provides swath data to a printhead driver controller 43 which controls printhead drivers 67 that drive the ink firing elements of printhead cartridges C1, C2, CN that are implemented as single color printhead cartridges and/or as multi-compartment cartridges, as described previously relative to FIGS 1-5. The printhead cartridges C1, C2, CN include respective printheads P1, P2, PN and respective nozzle arrays N1, N2, NN that emit a single color or multiple colors, wherein for example a nozzle array the emits multiple colors is arranged in subarrays that emit ink drops of respective colors.

[0022] It should be appreciated that the printhead cartridges C1, C2, CN can comprise printhead cartridges that receive ink from respective remote ink reservoirs R1, R2, RN, for example via ink delivery tubes as is

known in the art. Alternatively, the printhead cartridges can comprise self-contained printhead cartridges that have on-board ink reservoirs that are not coupled to remote ink reservoirs.

[0023] The print controller 61 further controls the media axis drive motor 152 which moves the print roller 154 (FIGS. 2 and 3) pursuant to media motion commands from the print controller 61. The media position encoder 156 provides information for the feedback control of the media axis drive motor 152. Similarly, a carriage axis encoder 73 provides feedback information for the feedback control of the carriage scan axis drive motor 112 which positions the ink jet cartridge supporting carriage assembly 100 (FIGS. 1-3) pursuant to carriage motion commands from the print controller 61. A multi-channel analog-to-digital (A/D) converter 75 receives analog signals based on the outputs of the optical sensor 200 and provides digital versions of such analog signals for processing to determine the printhead cartridge misalignments.

[0024] The print controller further receives the output of an optical drop detect circuit 49 that is used to identify any inoperative nozzles of the print cartridges C By way of illustrative example, the optical drop detect circuit 49 is implemented in accordance with the optical elements and the optical drop detect circuit disclosed in U.S. Patents 5,455,608 and 5,434,430, all incorporated herein by reference.

[0025] Referring now to FIG. 7, the printer forms an image by scanning the print carriage along the carriage axis and printing dots at selected pixel locations P of a two-dimensional pixel array A defined for the print media. The pixel locations or pixels P are arranged in rows and columns, wherein the rows are aligned with the carriage scan axis and the columns are aligned with the media axis. The number of pixels per unit distance along the carriage scan axis is referred to as the carriage axis resolution, while the number of pixels per unit distance along the media axis is referred to as the media axis resolution. The center to center distance between adjacent columns is the carriage axis dot pitch, while the center to center distance between adjacent rows is the media axis dot pitch. Any given row is printed in at least one pass or scan of the print carriage, and the media is appropriately advanced after at least one pass of the print carriage.

[0026] In accordance with the invention, inoperative (or bad) true black printing nozzles (of a single color ink cartridge or a multi-compartment ink cartridge) are detected, and dots that would normally be printed with the inoperative true black printing nozzles are printed as substitute dots using one or more non-black color printing nozzles (e.g., or a single color ink cartridge or a multi-compartment ink cartridge), whereby dots that are not true black are substituted for true black dots that would otherwise have been printed using inoperative true black printing nozzles if such nozzles were operative, and wherein a substitute dot comprises one or more constituent non-black dots, each constituent non-black dot being formed of non-black ink. Where the substitute dot is formed of a plurality of constituent non-black dots, the plurality of constituent non-black dots are overlapping and the substitute dot can be referred to as a composite substitute dot. By way of illustrative example, a constituent non-black dot can be formed of a single color such as cyan, magenta or yellow.

[0027] Effectively, one or more non-black color printing nozzles are substituted for inoperative true black nozzles as to the printing of dots that would otherwise be printed using inoperative true black printing nozzles if such nozzles were operative, wherein each of the substitute non-black color printing nozzles prints with non-black ink, such as cyan, magenta, or yellow. As a particular example, the substitute dots comprise process or composite black, wherein the substitute dots are printed using at least two non-black inks selected for example from cyan, magenta or yellow inks. As another example, the substitute dots comprise composite or process black formed of a cyan dot, a magenta dot and a yellow dot, all of which overlap.

[0028] Thus, substitute non-black printing nozzles print substituted dots at predetermined pixel locations. First substitute non-black printing nozzles of a first color can be disposed in a nozzle array that includes second substitute non-black printing nozzles of another color, for example in a multi-compartment cartridge. Third substituted non-black printing nozzles can also be disposed in the nozzle array that contains the first substitute non-black printing nozzles and the second substitute non-black print nozzles. Alternatively, substitute non-black printing nozzles of respectively different non-black colors can be disposed in respectively separate nozzle arrays, for example in respectively separate cartridges. By way of specific example, substitute cyan printing nozzles can be disposed in a nozzle array of a cyan printing cartridge, substitute magenta printing nozzles can disposed in a nozzle array of a magenta printing cartridge, and substitute yellow printing nozzles can be disposed in a nozzle array of a yellow printing cartridge.

[0029] Pursuant to the invention, visual effects of image defects due to inoperative true black printing nozzles are reduced without the use of throughput limiting print modes, so long as the non-uniformity introduced by using substitute dots is acceptable.

[0030] Referring now to FIG. 8, set forth therein is a flow diagram of an illustrative process of operating an ink jet printer in accordance with the invention. At 111 a user of the ink jet printer selects a desired print quality, for example, Best, Normal or Draft. At 113 inoperative true black printing nozzles are identified by the drop detect circuit 49 (FIG. 6). At 115 a determination is made as to whether the any black nozzles are inoperative. If no, then at 117 printing is performed using a standard print mode wherein substitute dots are not utilized. If the determination at 115 is yes, at 119 a determination is made as to whether the selected print quality is Best. If

yes, at 121 printing is performed using a multi-pass print mode to compensate for the inoperative black printing nozzles.

[0031] If the determination at 119 is no, at 123 printing is performed by using substitute dots formed of non-black ink for those dots that would normally be printed by the inoperative black printing nozzles if such nozzles were operative, wherein a substitute dot is formed of one or more non-black constituent dots. That is, one or more non-black printing nozzles are substituted for the inoperative true black printing nozzles.

[0032] The foregoing has been a disclosure of an ink jet printer wherein failed or inoperative black printing nozzles are compensated by substituting non-black printing nozzles for the failed black printing nozzles, which maintains throughput and provides for increased throughput as compared to compensation by multiple pass mode printing.

[0033] Although the foregoing has been a description and illustration of specific embodiments of the invention, various modifications and changes thereto can be made by persons skilled in the art without departing from the scope and spirit of the invention as defined by the following claims.

Claims

1. A method of operating an ink jet printer that includes a plurality of black printing elements and a plurality of non-black color printing elements, the method comprising the steps of:

   identifying inoperative black printing elements; and
   printing with a plurality of non-black printing elements substitute dots at predetermined pixel locations that would normally be printed with the inoperative black printing elements if such black printing elements were operative.

2. The method of Claim 1 wherein each of the substitute dots includes a constituent non-black dot having a color that is one of cyan, magenta and yellow.

3. The method of Claim 1 wherein each of the substitute dots comprises a plurality of overlapping constituent non-black dots.

4. The method of Claim 3 wherein the plurality of constituent non-black dots have different colors.

5. The method of Claim 3 wherein the plurality of constituent non-black dots includes a constituent cyan dot, a constituent magenta dot and a constituent yellow dot.

6. The method of Claim 1 wherein each of the substitute dots comprises a composite black dot.

7. The method of Claim 6 wherein the composite black dot comprises a plurality of overlapping constituent non-black dots.

8. The method of Claim 7 wherein the plurality of constituent non-black dots includes a constituent cyan dot, a constituent magenta dot and a constituent yellow dot.

9. The method of Claim 1 wherein the step of printing with the plurality of non-black printing elements includes the step of printing with first non-black printing nozzles disposed in a first nozzle array first dots of a first color at the predetermined pixel locations.

10. The method of Claim 9 wherein the step of printing with the plurality of non-black printing elements further includes the step of printing with second non-black printing nozzles disposed in a second nozzle array second dots of a second color at the predetermined pixel locations, wherein the second color is different from the first color.

11. The method of Claim 10 wherein the step of printing with the plurality of non-black printing elements further includes the step of printing with third non-black printing nozzles disposed in a third nozzle array third dots of a third color at the predetermined pixel locations, wherein the third color is different from the first color and the second color.

12. The method of Claim 1 wherein the step of printing with the plurality of non-black printing elements includes the steps of:

    printing with first non-black printing nozzles disposed in a nozzle array first dots of a first color at the predetermined pixel locations; and
    printing with second non-black printing nozzles disposed in the nozzle array second dots of a second color at the predetermined pixel locations, wherein the second color is different from the first color.

13. The method of Claim 12 further including the step of printing with third non-black printing nozzles disposed in the nozzle array third dots of a third color at the predetermined pixel locations, wherein the third color is different from the first color and the second color.

14. An ink jet printer comprising:

    a scanning print carriage
    a plurality of black printing nozzles supported by said scanning print carriage;

a plurality of non-black color printing nozzles supported by said scanning print carriage;
detection apparatus for detecting inoperative black printing elements; and
means for causing a plurality of non-black printing nozzles to print substitute dots at predetermined pixel locations that would normally be printed with the inoperative black printing elements if such black printing nozzles were operative.

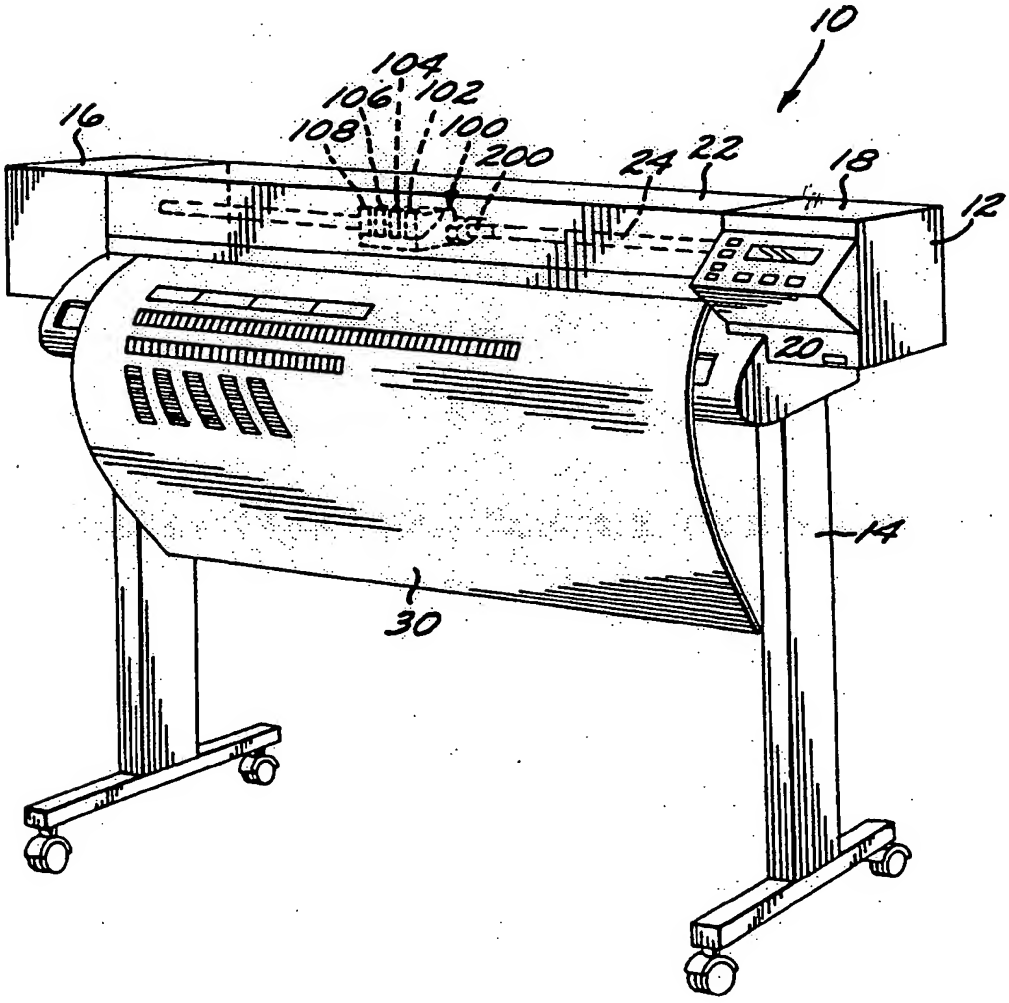
15. The ink jet printer of Claim 14 wherein said non-black color printing nozzles include cyan printing nozzles.

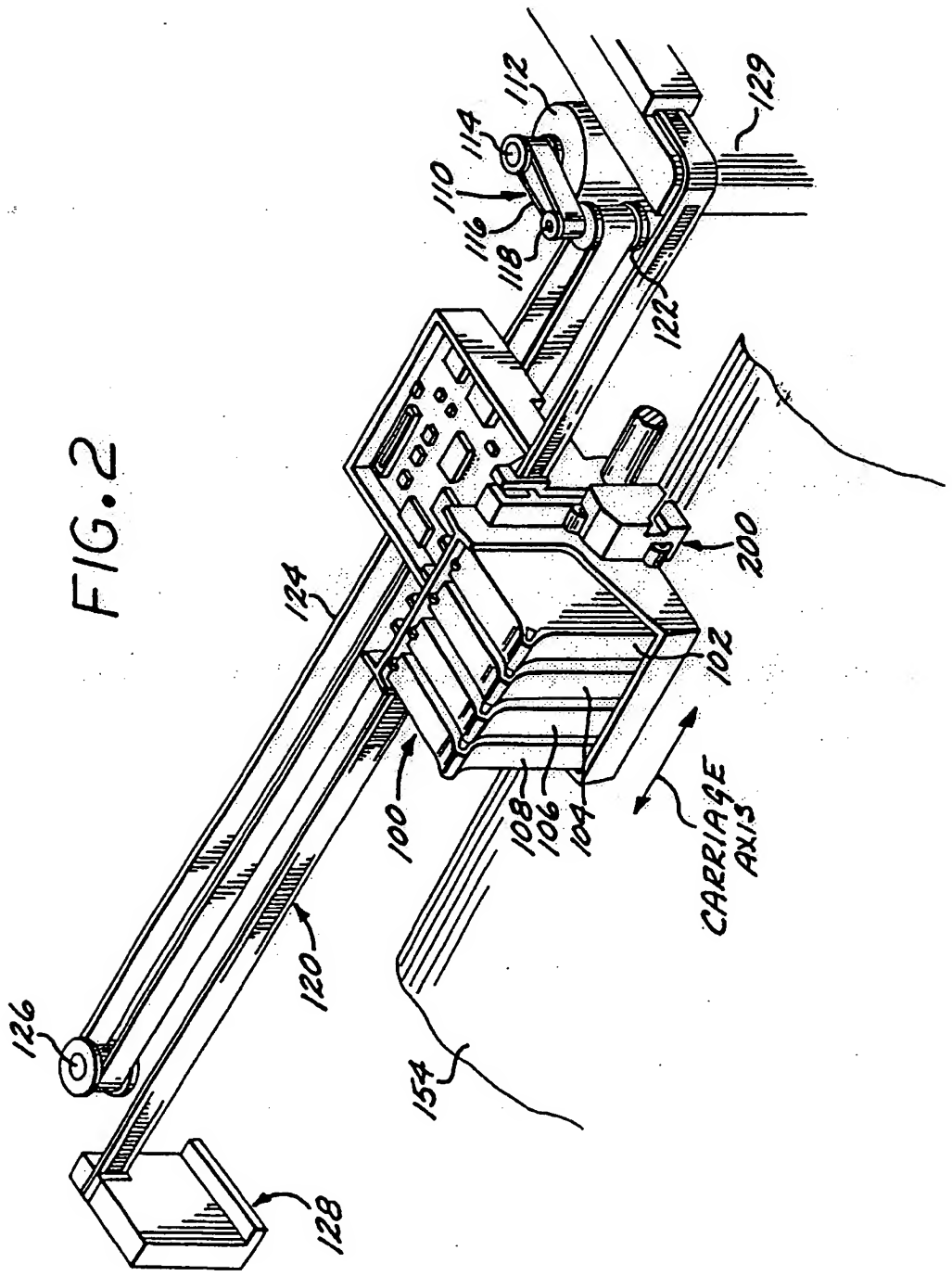
16. The ink jet printer of Claim 14 wherein said non-black color printing nozzles include magenta printing nozzles.

17. The ink jet printer of Claim 14 wherein said non-black color printing nozzles include yellow printing nozzles.

18. The ink jet printer of Claim 14 wherein said substitute non-black dots comprise process black dots.

FIG. 1




112
114
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122
200
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100
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106
104
CARRIAGE AXIS
120
126
154
128

FIG. 2

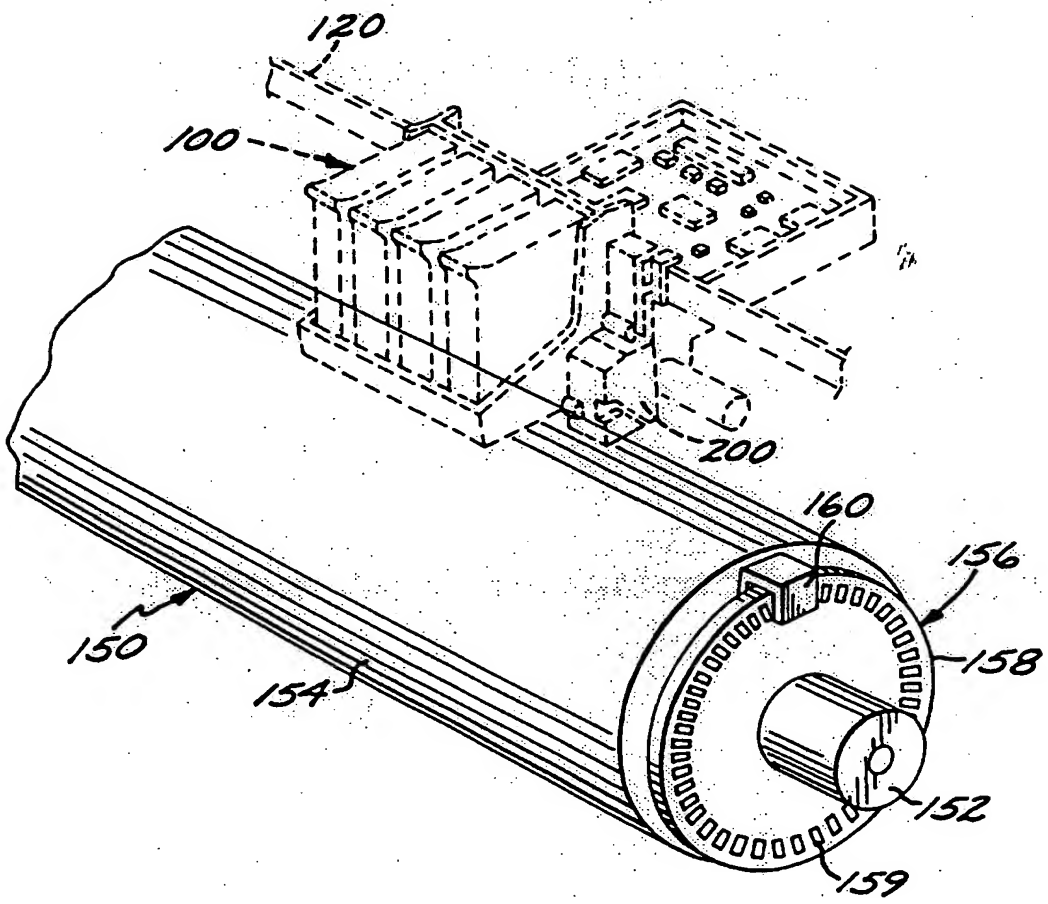


FIG. 3

FIG. 4

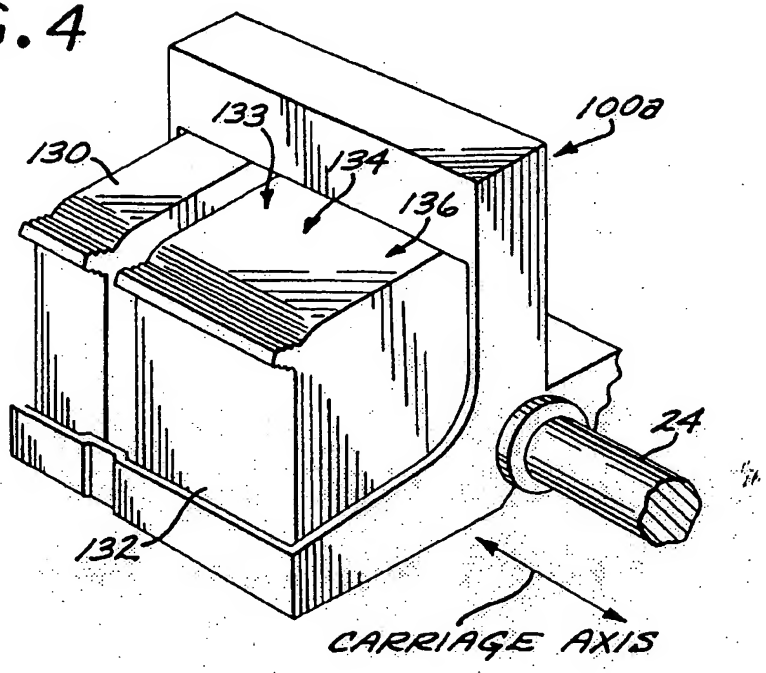
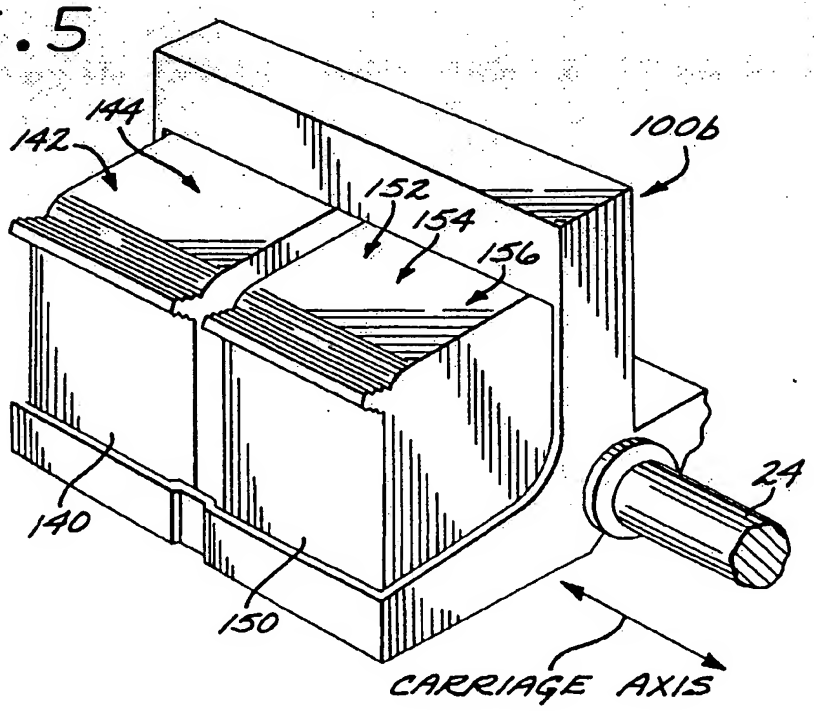
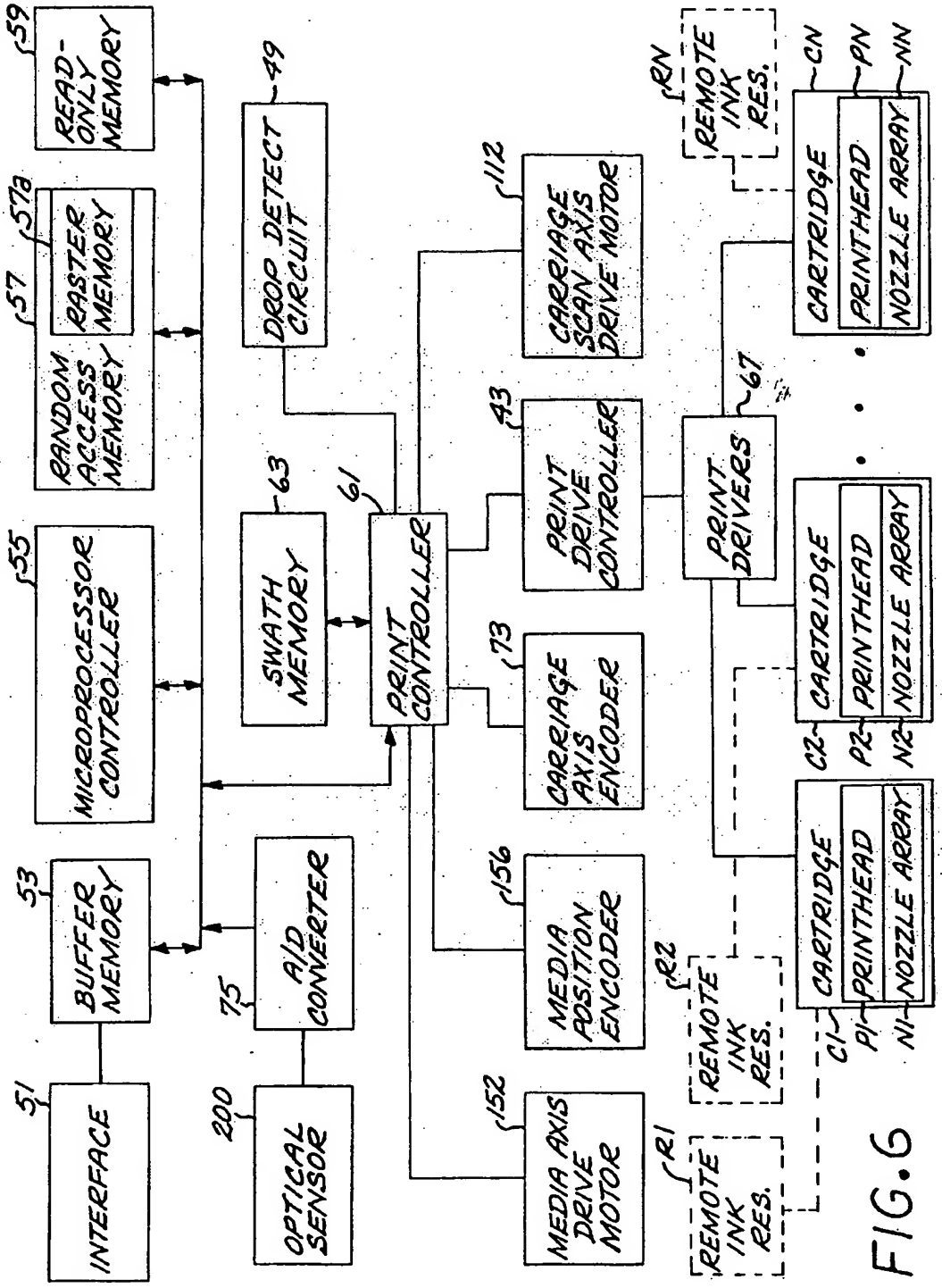

100a
133
130
134
136
24
132
CARRIAGE AXIS

FIG. 5


144
142
100b
152
154
156
24
140
150
CARRIAGE AXIS


59
READ-ONLY MEMORY
57a
RASTER MEMORY
57
RANDOM ACCESS MEMORY
55
MICROPROCESSOR CONTROLLER
53
BUFFER MEMORY
51
INTERFACE
49
DROP DETECT CIRCUIT
63
SWATH MEMORY
61
PRINT CONTROLLER
112
CARRIAGE SCAN AXIS DRIVE MOTOR
43
PRINT DRIVE CONTROLLER
73
CARRIAGE AXIS ENCODER
156
MEDIA POSITION ENCODER
152
MEDIA AXIS DRIVE MOTOR
75
A/D CONVERTER
200
OPTICAL SENSOR
RN
REMOTE INK RES.
67
PRINT DRIVERS
R2
REMOTE INK RES.
R1
REMOTE INK RES.
CN
PN
NN
CARTRIDGE
PRINTHEAD
NOZZLE ARRAY
C2
P2
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P1
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PRINTHEAD
NOZZLE ARRAY

FIG. 6

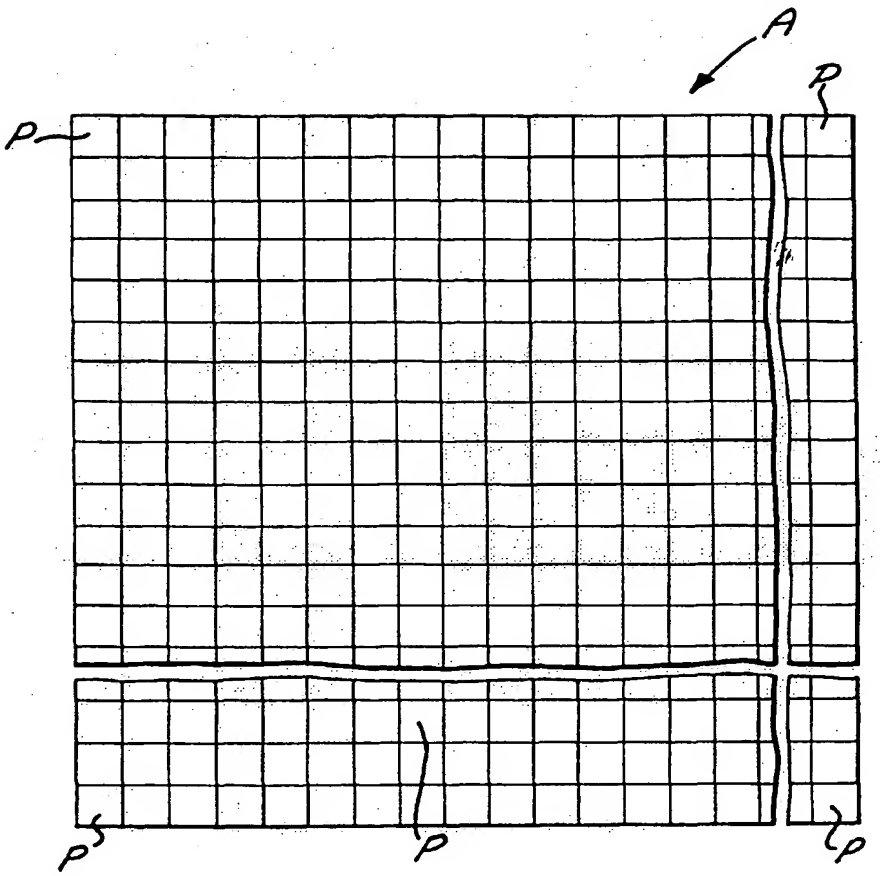

FIG. 7

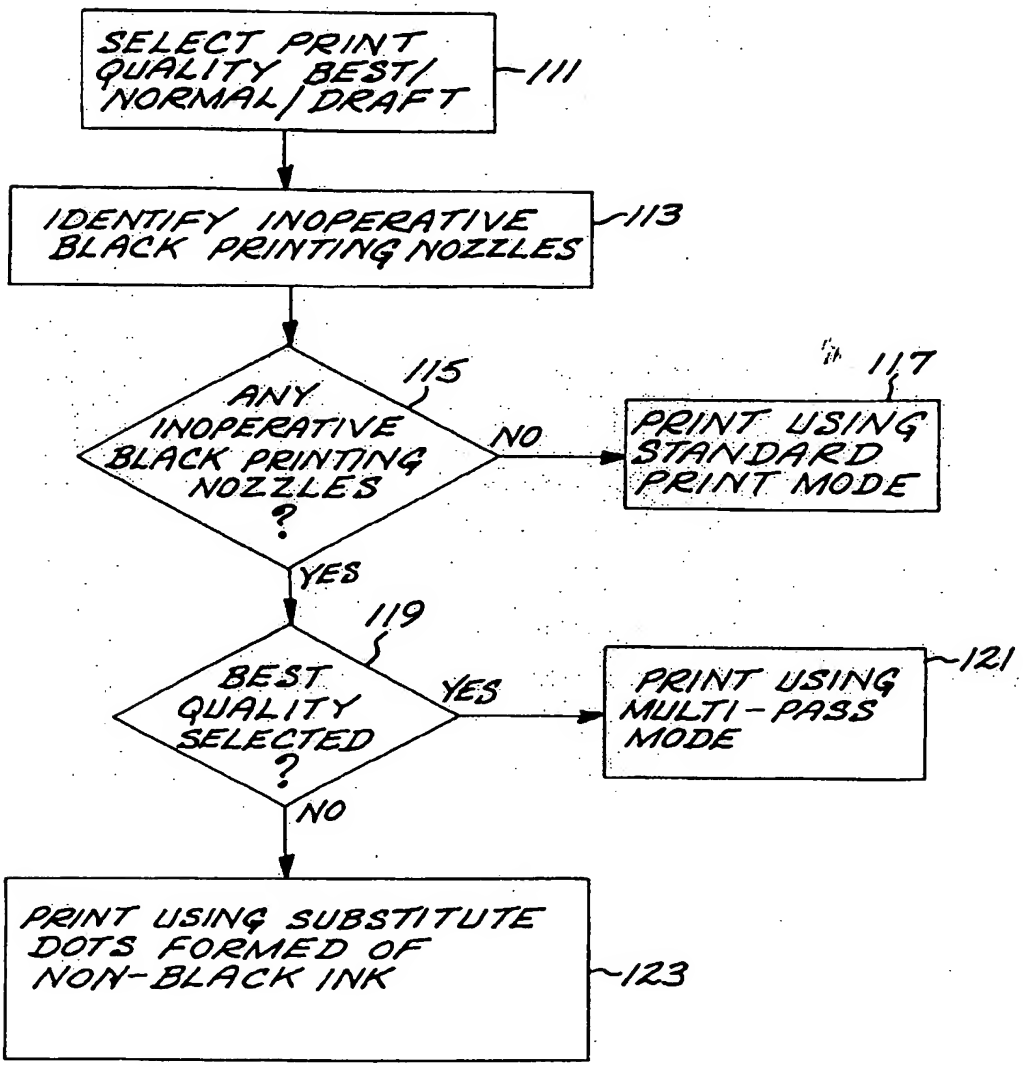
SELECT PRINT QUALITY BEST/ NORMAL/ DRAFT
111
IDENTIFY INOPERATIVE BLACK PRINTING NOZZLES
113
ANY INOPERATIVE BLACK PRINTING NOZZLES ?
115
NO
PRINT USING STANDARD PRINT MODE
117
YES
BEST QUALITY SELECTED ?
119
YES
PRINT USING MULTI-PASS MODE
121
NO
PRINT USING SUBSTITUTE DOTS FORMED OF NON-BLACK INK
123

FIG. 8